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Development and use of a RC divider for on-site calibration of MV measurement transformers

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Abstract Within the *Power & Energy Project* (WP5, Task 5.3) a resistive-capacitive divider for on-site indoor calibrations and measurements on the medium voltage grid has been designed, developed and characterised. With respect to conventional VTs, it has reduced dimensions, lower weight and, with the addition of external matching stages, low power output. The divider has been successfully experimented in the on-site calibration of two MV/LV VTs in indoor substations.

DESIGN PHASE

Design constraint

Quantity/parameter	Value	Quantity/parameter	Value
Rated primary Voltage U_p (rms)	30 kV	Max. power absorption	5 W
Rated secondary Voltage U_s (rms)	100 V	Frequency bandwidth	DC to 100 kHz
Ratio error (at 50/60 Hz)	≤0.5·10^{-3}	Environmental operating conditions	(-5 to 40) °C h_{rel} ≤ 90%
Phase displacement (at 50/60 Hz)	≤0.7 mrad	Overall Dimensions	(250 x 150 x 150) mm³

Resistors and capacitors for the high and low voltage arm

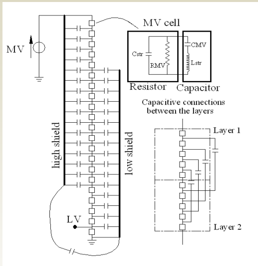
High voltage arm: (20 elements)

- R = 10 MΩ stray capacitances < 0.3 pF
  Temperature variation (20 ±25) °C ≤± 5 ppm/K
- C = 1.5 nF stray inductance < 3.4 nH
  Temperature variation(20 ±25) °C ≤± 10 ppm/K

Low voltage arm:

- R = 665.64 kΩ - stray capacitances negligible
  Temperature variation (20 ±25) °C ≤± 5 ppm/K
- C = 21.32. nF stray inductance negligible

Circuital model

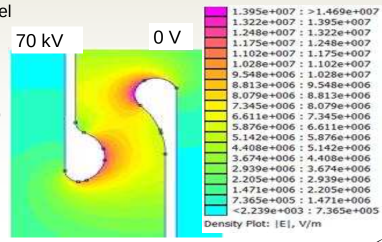


- The electric network is sketched as 20 MV cells and one LV cell (22 nodes).
- Each cell is made of one resistor and one capacitor parallel connected.

MV resistor ➡ parallel of resistance R_{MV} and capacitance C_{str}

MV capacitor ➡ series of capacitance C_{MV} and stray inductance L_{str}

- Coupling between components of adjacent layers (one layer = series of 5 cells), evaluated by 2D FEM model

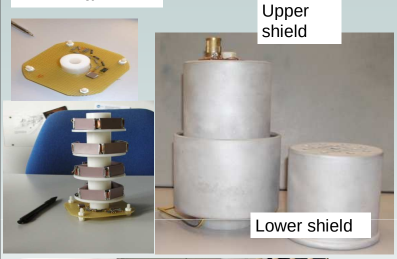


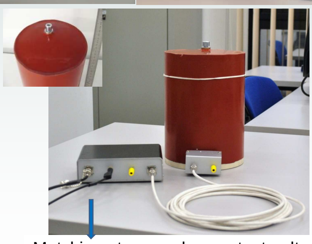
Shielding dimensioning

Solution of a FEM 2D axis-symmetric problem to identify electric field hot spots (insulating medium ε_r = 4.7, max. dielectric strength: 22 kV/mm).
Voltage between upper and lower shields: **70 kV**

Maximum electric field: **15 kV/mm**.

DIVIDER ASSEMBLY AND CHARACTERIZATION



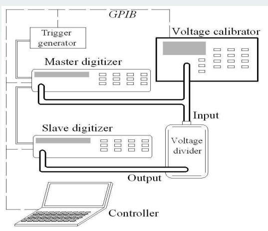


Matching stage: reduce output voltage level and improve frequency response

Final configuration

Dimensions: h=220 mm, ϕ=170 mm
Weight: 10 kg
Insulation: cast resin
Divider plus matching stage ratio: 30 kV/0.9 V

Acquisition and elaboration circuit



Characterisation tests

- Temperature dependence: measurement of divider+matching stage scale factor (SF) and phase displacement (PD) from 5 °C to 35 °C.
- Calculation and measurement of the frequency response from 10 Hz to 10 kHz. Relative deviation of the scale factor from the 50 Hz value within 5·10^{-3} up to 10 kHz.
- Determination of the scale factor and phase displacement at low and high voltage (50 Hz)
- Voltage linearity (up to 22 kV)

Uncertainty budget (50 Hz – on site VT calibration)

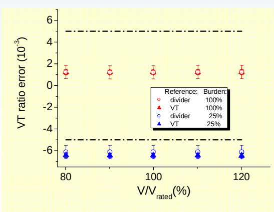
Quantity/Correction	Uncertainty contribution	
	Scale factor (·10^{-6})	Phase displac . (µrad)
SF/PD	125	42
Temperature	230	115
Linearity	42	31
Proximity	58	60
Stability	58	60
Expanded uncertainty (coverage prob. 95%)	**550**	**302**

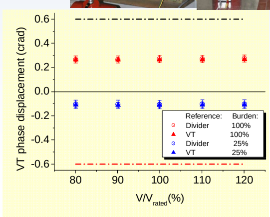
Determination of voltage linearity by comparison with a standard VT

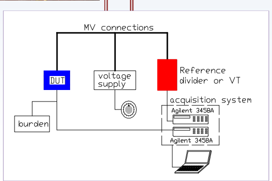
ON-SITE MEASUREMENTS

Calibration of a 6.3 kV /√3 /100 V /√3 V voltage transformer

- Location: 1.5 MVA MV/LV substation supplying INRIM buildings and labs
- Transformer under calibration: rated ratio 6.3 /√3 kV/100 /√3 V, 25 VA, class 0.5
- Calibration conditions: 0, 25% and 100% of the rated burden, cosβ=0.8
- Reference standard: a) RC divider
  b) reference TV
- Environmental conditions: θ=(15 to16)°C, h_{rel}= (30 to 49)%

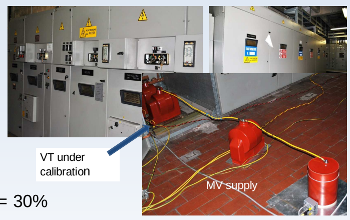


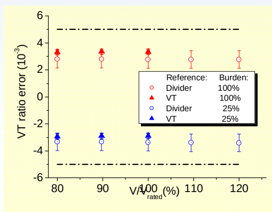


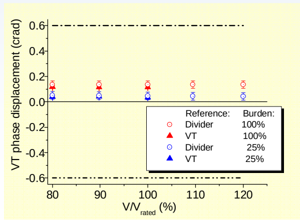


Calibration of a 22/√3 kV /100 V /√3 V voltage transformer

- Location: 1.25 MVA MV/LV substation supplying a short-circuit test laboratory
- Transformer under calibration: rated ratio 22/√3 kV/100 /√3 V, 50 VA, class 0.5
- Calibration conditions: 0, 25%, and 100% of the rated burden, cosβ=0.8
- Reference standard: a) RC divider
  b) reference TV
- Environmental conditions : θ=(19 to 20)°C, h_{rel}= 30%







Further developments and applications

The divider will be completed by an acquisition system for the digital conversion and signal transmission via optical fiber to make easier its on-site use and ensure galvanic isolation. Thanks to its rather flat frequency response up to some ten kilohertz it can be used, as an example, to measure square voltage waveforms for railway electrical engines.

The application of the developed device both for on-site calibration and measurement is planned within the EMRP Joint Research Project *Smart Grid* recently started.